A new species of king cricket *Glaphyrosoma* Brunner von Wattenwyl, 1888 (Orthoptera: Anostostomatidae: Glaphyrosomatini) from Costa Rica with behavioral observations

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**Abstract**

A new king cricket species *Glaphyrosoma stephanosoltis* sp. nov. (Orthoptera: Anostostomatidae: Glaphyrosomatini) from mid-elevation tropical rainforests of Costa Rica is described. This new species represents the southernmost distribution of the genus *Glaphyrosoma* Brunner von Wattenwyl, 1888, which is widely distributed throughout Mexico, Guatemala, and Honduras. Biology of the new species is briefly described.

**Key Words:** new species, feeding biology, Central America

**Introduction**

The king cricket genus *Glaphyrosoma* Brunner von Wattenwyl, 1888 (Orthoptera: Anostostomatidae) includes medium-sized apterous insects endemic to Mexico and Central America, mostly found in mid-elevation forests and lowlands (Cadena-Castañeda & Monzón-Sierra, 2017). *Glaphyrosoma* is characterized by the lack of subapical spines on the dorsal surface of the fore tibiae and a feather-like relief of the outer surface of hind femora (Gorochov & Cadena-Castañeda, 2016) and poorly developed prosternal spines (Cadena-Castañeda & Monzón-Sierra, 2017). Not much is known about the biology of these insects. Currently, the genus is placed in the tribe Glaphyrosomatini, which includes two genera, *Glaphyrosoma* and *Cnemottetix* Caudell, 1916 (Rentz and Weissman, 1973; Johns, 1997; Cigliano et al., 2019), characterized by complete aptery in both sexes, smooth fastigium of vertex, absence of armature on the dorsal surface of the fore tibiae, extraordinarily long maxillary palpi possibly associated with silk production (only verified in *Cnemottetix*) and abdominal stridulatory apparatus (Rentz and Weissman, 1973). Based on a molecular phylogeny of Stenopelmatoidea, Vandergast et al. (2017) recovered Glaphyrosomatini as a monophyletic group, but its phylogenetic position within Anostostomatidae remains unclear.

which was described from the Celaque National Park in the western part of Honduras, \textit{Glaphyrosoma} has never been described from other Central American countries including El Salvador, Nicaragua, Costa Rica, and Panama. However, these countries have not been thoroughly explored to understand the diversity of \textit{Anostostomatidae}, and it is possible that more species of \textit{Glaphyrosoma} may await descriptions.

Here we describe a new species of \textit{Glaphyrosoma} from mid-elevation rainforest of Costa Rica, representing a new southern limit for the genus. In a survey of Costa Rican Orthoptera, Barranco (2010) reported 1 nymph and 1 female of \textit{G. gracile} from the Reserva Biológica Alberto Manuel Brenes, but Cadena-Castañeda & Monzón-Sierra (2017) suggested that the Costa Rican specimens were either erroneously identified or would represent an undescribed species because of the known geographical distribution of the genus. We have collected a large series of specimens, including both sexes as well as nymphs, from the Soltis Center for Research and Education located in San Juan de Peñas Blancas in San Ramón. We have compared our specimens with the descriptions of other known species of \textit{Glaphyrosoma} published in Gorochov & Cadena-Castañeda (2016) and Cadena-Castañeda & Monzón-Sierra (2017), and there is no doubt that the new species belongs to \textit{Glaphyrosoma} and that it represents a previously undescribed species. In addition to the species description, we also present novel field observations to increase our understanding of the biology of these fascinating insects.

Materials and Methods

\textbf{Descriptive Taxonomy.} All descriptions followed the terminology and style utilized by Gorochov & Cadena-Castañeda (2016) and Cadena-Castañeda & Monzón-Sierra (2017). All specimens were collected in August 2018 by the authors at night within the rain forest trails of the Soltis Center for Research and Education in San Juan de Peñas Blancas, San Ramón, Costa Rica. They were only active after it had rained or was sprinkling slightly, and were easily attracted to oatmeal baits. A total of 19 adults and 8 nymphs were collected and preserved in 80% ethanol in the field and taken back to Texas A&M University, College Station, Texas, USA. The specimens were examined using a Leica M205A stereoscope. The specimens were properly pinned and labeled, and all resulting specimens were deposited to the Texas A&M University Insect Collection.

\textbf{Dissection and Measurement.} Male genitalia were extracted by cutting the last three abdominal segments of adult male specimens using dissecting scissors. The tissue was placed into a 10% KOH solution overnight to dissolve muscle tissues. After photographs were taken, the dissected specimens were preserved in glycerin in genital vials and pinned beneath the respective specimens. We used Mitutoyo CD-6” CS digital caliper to measure various body parts. For each measurement, five adult males and females including both holotype and female were used. Each body part was measured three times to account for measurement error, and the mean value was used for subsequent calculations.

\textbf{Digital Imaging and Illustration.} Photographs were taken using a Visionary Digital LK imaging system equipped with a Canon EOS 6D DSLR camera combined with a 50mm/65mm/100mm lens to take multiple images at different focal lengths. The resulting files were converted from RAW to TIFF format using Adobe Lightroom (v.4.4), stacked into a single composite image using Zerene Stacker (v.1.04), and then Adobe Photoshop CS6 was used to add a scale bar and adjust light levels, background coloration, and sharpness as needed. Line drawings were made using a Leica MZ16 stereoscope with a camera lucida attached. Drawings were scanned and cleaned in Adobe Photoshop CS6.

\textbf{DNA Barcode.} We generated 658 bp DNA barcode from the new species following a standard barcoding protocol. In short, we extracted DNA from hind femur muscle tissue from one nymphal specimen preserved in 100% ethanol using Gentra Puregene kit (Gentra Systems Inc.). We performed a polymerase chain reaction using Folmer primers (Folmer, 1994) to amplify a barcoding region fragment of mitochondrial cytochrome c oxidase I (COI) gene and sequenced using Applied Biosystems Hitachi 3500 Genetic Analyzer (Applied Biosystems™).

\textbf{Type Material.} Type material was deposited in the Texas A&M University Insect Collection (TAMUIC) at Texas A&M University, College Station, Texas, U.S.A.
Results

Taxonomic Description

Family Anostostomatidae Saussure, 1859

Tribe Glaphyrosomatini Rentz & Weissman, 1973

*Glaphyrosoma* Brunner von Wattenwyl, 1888

*Glaphyrosoma stephanosoltis* Richardson, Trimm, Paderes, Koehl, & Song, sp. nov.
Fig. 1–11

urn:lsid:Orthoptera.speciesfile.org:TaxonName:506875

**Diagnosis.** *Glaphyrosoma stephanosoltis* sp. nov. is dorsally colored in solid dark brown (Figs. 1, 3, 10), and is similar in overall coloration to *G. gracile, G. anderi, G. beretka, G. bulbosum, G. pushenkovi, G. franciscoasturiasi, G. hectorcenteno,* and *G. magnaproctalis.* However, it can be separated from all other members of the genus by having quadrangular male paraproctal process with a spine protruding medially facing upwards (Figs. 7B, 7C, 9A, 9D). This species is morphologically most similar to *G. magnaproctalis* according to the key presented by Cadena-Castañeda & Monzón-Sierra (2017), but differs in the position of the spine on male paraproctal process and the appearance of the male subgenital plate as well as the length of styli. The spine arises medially in *G. stephanosoltis* sp. nov. instead of being located at the top of the paraproctal process. The subgenital plate also shows more curvature between the styli forming a deep “V” shaped notch half the length of the subgenital plate (Fig. 7D, 9B) and differs from the subgenital plate of *G. magnaproctalis* in which there is almost no notch in between the styli.

**Coloration.** Dorsal portion of head dark brown, nearing black; gena and frons dark brown; clypeus light yellow. Median ocellus and two upper ocelli pinkish cream white (when alive) with light beige rings (Fig. 1). Antennae dark brown. Labrum white (when alive); mandibles light brown at base and dark brown at the tip; maxillary palpi and labial palpi creamy white. Entire dorsal region from thorax to abdomen dark brown with no delineated coloration patterns. Lateral margin of thoracic and abdominal tergites lighter brown. Sternum yellow/brown. Fore femora and mid femora yellowish brown distally, and darker brown apically. Hind femora lighter brown distally, gradually becoming darker apically and dorsally, with apical end (knee) abruptly becoming creamy white (Fig. 1). All tibiae distally dark brown, apically creamy white. All tarsi creamy white.

**FIGURE 1.** Habitus of live specimens of *Glaphyrosoma stephanosoltis* sp. nov. taken in the field. (A) dorso-lateral view; (B) frontal view.
Male. Head (Fig. 2A,B): Integument smooth. Vertex smooth without any depression, blended to frontal ridge. Gena convex. Frons, smooth, unpronounced, blended with the rest of head; two parallel depressions starting at the base of scape; a pair of small circular depressions above the mandibular condyles. antennal scape originating from where frontal ocellus is positioned. Antenna filiform and at least three times longer than body. Ocelli round and not protruding from head. Eyes pear-shaped, narrowing dorsoventrally, half as long as the width of gena. Clypeus upside down triangular with broadly round ventrally, concave. Labrum circular. Mandibles narrowing to sharp end, articulation points pronounced below gena. Maxillary palp very long, nearly three times the dorsoventral length of the head. Labial palp evident, but not long, shorter than the length of mandible. Both maxillary and labial palp with bulbous apical tips. Thorax: Integument smooth. Completely apterous. Pronotum about as long as wide (Fig. 3A); sloping downward anteriorly; lateral lobe of pronotum square basally (Fig. 2B). Mesonotal and metanotal lobes rounded distally (Fig. 2B). Legs: Fore tibiae ventrally with 3 pairs of symmetrically arranged spines, 6 apical spurs composed of 1 pair of short symmetrical spines and 2 pairs of apical spurs (Figs. 4A, 5A); no subapical spines along the dorsal surface; tympanum present as depression at distal portion of inner and outer surface of fore tibiae (Fig. 5A). Middle tibiae with 4 asymmetrical spines dorsally and 3 pairs of symmetrically arranged spines ventrally (Fig. 4B); 6 apical spurs composed of 1 pair of short symmetrical spines, 1 pair of spurs dorsally, and 1 pair of spurs ventrally (Fig. 4B). Hind tibiae dorsally armed with 18–21 unarticulated spines, 8 apical spurs composed of 1 pair of short spines, 1 pair of short spurs ventrally, two pairs of long spurs (Fig. 4C). Hind femora absent of stripes or patterns (Fig. 3A); light muscular lining visible through cuticle (Fig. 3A); femoral groove present on outer side of hind femur from base to distal part (Fig. 3A). Inner side of hind femora with 3–4 diagonal rows of stridulatory pegs present (Fig. 6C). Abdomen: Integument smooth. Abdominal tergites gradually narrowing to last tergite (Fig. 3B). Sternites rectangular and wider than its length. Lateral margin of first and second abdominal tergites with patches of granular stridulatory pegs (Fig. 6A). The ninth tergite broadly bilobed and divided in the middle with a broad notch along the postero-medial margin (Figs. 7C, 9A, 9B). The tenth tergite forming a pair of hooks in the middle, which turn upward above the middle of the ninth tergite (Figs. 7B, 7C, 9A, 9C). Paraproct projected posteriorly but distal part still remains very close to last abdominal tergite and almost flat in appearance (Figs. 7B, 9A). Paraproctal process rectangular with a small denticle arising from medio-posteriorly lying almost flat and directed upwards (Figs. 7B, 9A, 9D). Subgenital plate with a prominent “V” shaped posteromedian notch and relatively long styli half the length of the subgenital plate (Figs. 7D, 9B). Cerci almost twice as long as the width of the tenth tergite, tapering from the base to the tip, arched inwards in dorsal view, covered in small hairs (Figs 7A, C, D). Male internal genitalia largely membranous and as in Fig. 8.

Female. Similar to male (Fig. 10). Subgenital plate triangular with a broad base and tapering toward the tip (Fig. 9E). Ovipositor curved medially and apically directed (Fig. 11) and almost one-third length of hind femora. Paraproctal process absent. Cerci thicker than male cerci at base with prominently tapering to the tip (Fig. 11).
FIGURE 3. Holotype of *Glaphyrosoma stephanosoltis* sp. nov. (A) lateral view; (B) dorsal view.

FIGURE 4. Legs of *Glaphyrosoma stephanosoltis* sp. nov. (A) fore tibia to tarsi; (B) mid femur to tarsi; (C) Hind tibia to tarsi.
FIGURE 5. Tibial tympana of Glaphyrosoma stephanosoltis sp. nov. (A) male, showing outer tympanum in the right fore tibia and inner tympanum in the left fore tibia; (B) female outer tympanum; (C) female inner tympanum.

FIGURE 6. Stridulatory apparatus of Glaphyrosoma stephanosoltis sp. nov. (A) male and (B) female, arrows pointing to patches of granular stridulatory pegs in the first and second abdominal tergites; (C) male and (D) female, arrow pointing to diagonal rows of stridulatory pegs in the inner side of hind femur.
FIGURE 7. Male external genitalia of Glaphyrosoma stephanosoltis sp. nov. (A) lateral view of abdominal segments 4–10; (B) posterior view of abdomen, showing cerci, paraproctal processes, and tenth tergites; (C) dorsal view of ninth and tenth abdominal tergites; (D) ventral view showing male subgenital plate.

Measurements (in mm). Male (n=5): pronotum length 8.94–9.42 (9.24 ± 0.22); fore femur length 11.89–12.62 (12.23 ± 0.29); mid femur length 12.09–13.63 (12.87 ± 0.59); hind femur length 29.36–31.31 (30.02 ± 0.89); hind femur width 6.71–6.83 (6.78 ± 0.06). Female (n=5): pronotum length 9.00–10.24 (9.60 ± 0.48); fore femur length 11.33–13.55 (12.33 ± 0.84); mid femur length 11.96–13.65 (12.79 ± 0.67); hind femur length 28.53–31.73 (30.15 ± 1.29); hind femur width 6.50–7.60 (7.05 ± 0.40); ovipositor length 11.74–13.95 (12.56 ± 0.82).

Etymology. From Latin “stephano” meaning crown and “soltis” referring to the Soltis Center for Research and Education, the type locality of the species. Therefore, stephanosoltis means “Crown of Soltis” referring to the first king cricket ever described at the facility.


Holotype: Male (Fig. 3). (Measurement: pronotum length 9.34 mm; fore femur length 11.99 mm; mid femur length 12.09 mm; hind femur length 29.36 mm; hind femur width 6.81 mm.) COSTA RICA: Alajuela Province, San Ramón, San Juan de Peñas Blancas. Soltis Center for Research and Education, 10°23'0.4524”N, 84°37'4.674”W, 7.viii.2018, collected by hand at night. Coll. S.J. Richardson.
**FIGURE 8.** Male internal genitalia of *Glaphyrosoma stephanosoltis* sp. nov. (A) male internal genitalia in their natural position inside abdomen, showing their relative position to the subgenital plate; (B) dissected and magnified view of male internal genitalia.

**Additional Type Material.** 26 paratypes (5 adult males, 13 adult females, 5 nymphal males, 3 nymphal females). Same data as holotype.

**Type Depository.** All type material has been deposited to the Texas A&M University Insect Collection (TAMU-IC).

**DNA Barcode.** We have generated a DNA barcode for *G. stephanosoltis* sp. nov., which has been deposited to GenBank with accession number MN128722, and the DNA tissue voucher specimen was deposited to TAMUIC Insect Genomic Collection with voucher number TAMUIC-IGC-002678. Although Vandergast et al. (2017) generated COI genes for many Anostostomatidae, including several unidentified specimens of *Glaphyrosoma* from Mexico, the primers that they used (C1-J-2183 and C1-N-2872) amplified the back half of the COI gene and did not overlap with the DNA barcode region, which is located in the front half of the COI gene. Therefore, our DNA barcode represents the first for the genus.

**Biological Information.** *Glaphyrosoma stephanosoltis* sp. nov. was hand collected along the trails adjacent to secondary rainforest in the vicinity of the Soltis Center for Research and Education. The Soltis Center’s forests are adjacent to the Children’s Eternal Rainforest (Bosque Eterno de los Niños) and located about 450 m above sea level. The insects were only found after sunset when it was sprinkling or after it had just rained, and were more abundant when temperature was above 21°C. The species was never observed during the day, and when kept in a screen cage with foliage comprised of torn leaves and branches, it was observed that the insects still hid under foliage, even in a dark environment. Those that were unable to hide under the foliage started to appear dull in their cuticles, which suggested that they desiccate easily even on the rainforest floor. The species most likely lives underground in order to avoid desiccation and remain in a higher level of humidity beneath the rainforest floor and only comes out when humidity levels are higher to search for food or mates. When collecting specimens along trails, it was found they tended to hide on the overhanging dirt underside along trails and sometimes in tunnels most likely made by other burrowing animals. When baited with oatmeal, the insects were attracted within an hour of placing the bait, which suggested that these insects might be targeting a good source of carbohydrate and protein, which are rich in the oatmeal used for the trail. When presented with a choice between a plant mixture (*Passiflora* sp., *Cecropia obtusifolia*, *Neurolaena lobata*, and unidentified Piperaceae) and a protein mixture (land crab and katydids), all of which were commonly found in the forest, *G. stephanosoltis* sp. nov. showed overwhelming preference for the plants. However,
when kept in a cage with other insects, they fed on dead crickets and katydids, suggesting a necrophagous behavior. Collectively, these observations suggest that *G. stephanosoltis* sp. nov. is an omnivorous insect, which is a common dietary pattern in many ensiferans.

**FIGURE 9.** (A) posterior view of male external genitalia showing paraproctal processes; (B) ventral view of male subgenital plate; (C) lateral view of male ninth and tenth abdominal tergites; (D) lateral view of male paraproctal process; (E) ventral view of female subgenital plate.

**Discussion**

Commonly known as king crickets and wetas, the family Anostostomatidae is found mostly in the Southern Hemisphere, including South America, Australia, New Zealand, and southern Africa (Field, 2001; Cadena-Castañeda & Cortés-Torres, 2013). The current distribution of the family can be characterized as a Gondwanan distribution, and Song *et al.* (2015) estimated the family to have originated in the Mezozoic. Therefore, the family’s presence in the Central America can be attributed to a possible northern colonization from the south. The tribe Glaphyrosomatini includes *Glaphyrosoma*, which is known from Mexico, Guatemala, Honduras (Gorochov & Cadena-Castañeda, 2016; Cadena-Castañeda & Monzón-Sierra, 2017), and Costa Rica (this study), and *Cnemotettix*, which is found in southern California and Mexico (Rentz and Weissman, 1973; 1981). Therefore, the tribe can be considered the most northerly-distributed member of the family, and *G. stephanosoltis* sp. nov. represents the southernmost distributed member of the tribe.
**Glaphyrosoma** is a forest-dwelling genus, with a possibly fossorial habit although there is no direct observation about its behavior. The genus belongs to the same tribe as *Cnemotettix* and shares the extraordinarily long maxillary palpi with enlarged and bulbous tips (Rentz and Weissman, 1973) (Fig. 2). In *Cnemotettix*, the maxillary palpi are known to have silk glands at the tip, which are used for gluing and sewing small packets of sand grains that make up the wall or ceiling of its burrow (Rentz and Weissman, 1973). Based on morphology of the maxillary palpi alone, *Glaphyrosoma* is likely to have the same silk-spinning ability, but direct evidence is currently lacking (Vandergast et al. 2017).

*Glaphyrosoma* species, including *G. stephanosoltis* sp. nov., have a stridulatory apparatus involving the first and second abdominal tergites and hind femora (Fig. 6). Although sound production in *Glaphyrosoma* is unknown (Vandergast et al. 2017), it is conceivable that it has a similar mechanism to the New Zealand wetas, which can produce sound primarily by rubbing pegs on the inner surface of the hind femora against the stridulatory pegs on the abdomen (Field, 1993). However, unlike most singing insects in which only males produce sound for the purpose of mate calling, both males and females of *Glaphyrosoma* have the stridulatory apparatus, and it is possibly used for producing defensive calls, similar to what is known in wetas (Field, 1993, 2001). It is known that males of *Glaphyrosoma* species drum with hind legs (Weissman, 2001, Vandergast et al., 2017).

Although Costa Rica is well-known for its insect biodiversity, its orthopteran fauna is only partially known. Although Naskrecki (2005) reviewed a tettigoniid subfamily Conocephalinae, Otte (2006) reviewed crickets from La Selva, and Rowell (2013) reviewed most of Caelifera, not much is known about the remaining orthopteran families. Prior to the present study, the only member of Anostostomatidae known from Costa Rica has been the genus *Anabropsis* Rehn, 1901, which is widely distributed from Mexico to Colombia, with 5 species represented in Costa Rica. Vandergast et al. (2017) included an unidentified Anostostomatidae listed as “new genus Costa Rica” in their phylogenetic analysis, which was found to be closely related to the tribe Glaphyrosomatini, but the identity has not...
been confirmed. Our study now adds a definite second (and possibly a third) genus of Anostostomatidae known in Costa Rica. *Glaphyrosoma stephanosoltis* sp. nov. is locally abundant and quite easy to find. It is puzzling how this large species has remained undescribed until now, but it opens up a possibility that there might be more species of *Glaphyrosoma* waiting to be discovered given numerous forests that have not been explored in search of these insects.

**FIGURE 11.** Female ovipositor of *Glaphyrosoma stephanosoltis* sp. nov. (A) lateral view of ovipositor; (B) dorsal view of female abdominal terminalia showing cerci and ovipositor.
Acknowledgments

We would like to thank the Department of Entomology at Texas A&M University for giving us the opportunity to have a study abroad course (ENTO 489 – Field Entomology in the Tropics, Summer 2018) at the Soltis Center for Research and Education in Costa Rica as well the staff of the Soltis Center for providing us with an exceptional experience. We would also like to thank Dr. Spencer Behmer for his guidance on the feeding behavior and biology of Orthoptera, Brandon Woo for taking digital images of the stridulatory apparatus, Phillip Shultz for assistance with sequence data generation, and David Weissman for providing valuable comments in the earlier draft of this manuscript. The specimens were collected under MINAE CONAGEBIO permit #R-16-2016-OT-CONAGEBIO.

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